APPENDIX I

ORR BIOSOLIDS LAND APPLICATION SITE AIR DISPERSION MODEL

OFFSITE DOSE IMPACT FROM DISPERSION OF RADIONUCLIDES FROM LAND APPLICATION SITE

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OFF-SITE RISK AND DOSE IMPACTS

The Department of Energy (DOE) carefully monitors the off-site consequences of operations at the Oak Ridge Reservation. The National Emissions Standards for Hazardous Substance regulations establish an off-site does limit of 10 mrem/year (10 CFR 62) for all emissions at DOE facilities; however, it is DOE policy (DOE Order 5400.5) to maintain radiological doses to the public As Low As Reasonably Achievable (ALARA). For example, the 1999 DOE Oak Ridge Reservation (ORR) Annual Site Environmental Report (ASER) indicates that the calculated radiation dose to maximally exposed off-site individuals from airborne releases to be 0.007 mrem, total effective dose equivalent (TEDE). The purpose of the following dose/risk model is to evaluate the maximum potential contribution the land-application of municipal sewage sludge has to the ORR's total dose impact to the public.

Air dispersion is the primary mechanism for off-site release of radioactive material contained in land applied sludge. To model the potential impact of land applied sludge, off-site risk and doses were estimate using an EPA (1991) recommended particulate emission factor (PEF). The PEF relates the contaminant concentration in soil with the concentration of respirable particles in the air due to fugitive dust emissions from surface contamination sites. The PEF (***Exhibit I.1.***) provides a simple, but conservative estimate of the particulate flux between the soil and air. It does not take into account other factors such as dispersion, mixing, and particle precipitation that attenuate radionuclide concentrations as particles of soil are transported off site. The particulate emissions from contaminated sites are due to wind erosion and, therefore, depend on the erodibility of the surface material. The PEF models a surface with unlimited erosion potential, that is characterized by bare surfaces of finely divided material such as sandy agricultural soil with a large number ("unlimited reservoir") of erodible particles. Such surfaces erode at low wind speeds, and particulate emission rates are relatively time-independent at a given wind speed. Exhibit 1 presents the PEF equation, default values necessary to calculate the flux rate for an "unlimited reservoir" surface (i.e., G, U_m , U_t , and F(x)) are EPA (1991), and the remaining input values appropriate to the site. The average wind speed of 6.9 m/s is the 1999 National Weather Service estimate. Area of contamination is considered to be one acre, a reasonable size application area. Most of the sites are densely vegetated, particularly in summer months; however, it is conservatively assumed that half the site is exposed soil.

Table I.1. Dose and Risk Estimates for Inhalation Exposure Route

Radio-Nuclide	Activity (pCi/g)	Activity Air (pCi/m^3)	Intake pCi	h_i (mrem/pCi)	Dose (mrem)	Risk
^{60}Co	0.214	1.18E-07	8.08E-04	1.92E-05	1.55E-08	5.67E-14
^{137}Cs	0.083	4.57E-08	3.20E-04	3.19E-06	1.05E-09	6.11E-15
^{235}U	0.016	8.81E-09	6.16E-05	1.23E-02	7.56E-07	8.01E-13
^{238}U	1.861	1.02E-06	7.17E-03	1.18E-02	8.48E-05	8.89E-11

The annual dose to an off-site receptor was estimated using maximum predicted activities for ^{60}Co, ^{137}Cs, ^{235}U, and ^{238}U that are reported for the Rogers Site (the most heavily loaded site) in ***Appendix E*** of the *Environmental Assessment for Proposed Changes to Sanitary Biosolids Land Application Program on the Oak Ridge Reservation* (DOE 2003). The main exposure routes used to estimate an annual dose include inhalation and external exposure.

EXHIBIT I.1.: PARTICULATE EMISSION FACTOR

$$PEF\ (m^3/kg) = \frac{LS \times V \times DH \times 3600\ s/hr \times 1000\ g/kg}{A \times 0.036\ (1-G)\ (U_m/U_t)^3 \times F(x)}$$

Parameter	**Definition and units**	**Values**
LS	width of contaminated area (m)	63.6
V	wind speed in mixing zone (m/s)	2.25
DH	diffusion height (m)	2
A	area of contamination (m^2)	4046.8
0.036	respirable fraction (g/m^2-hr)	0.036
G	fraction of vegetative cover (unitless)	0
U_m	mean annual wind speed (m/s)	6.9
U_1	equivalent threshold value of wind speed at 10 m	12.8
F(x)	function dependent on U_m/U_1 (unitless) (EPA 1991)	0.0497

The dose and risk to off-site receptors was modeled according to the parameters listed in ***Exhibit I.2.*** and the soil activities listed in ***Table I.1***. Intake (pCi) estimates included a correction for radioactive decay over the period of a year. The dose coefficient (h_i) for inhalation were taken from EPA (1988) and include the effects of daughter products generated once the parent radionuclide is inhaled. Risk values were estimated for comparison using the slope factors reported in (EPA 1995). Risk values are several orders of magnitude below the recommended EPA 10^{-6}-10^{-4} acceptable levels for life time exposure. (Note that since these values are for one year of exposure, life time risk can be estimated by multiplying these values by 70 years, still leaving risks less than 10^{-8}.)

For external exposure through immersion in air, it was assumed that the daughters were all in secular equilibrium and no attempt was made to estimate the effects of differential weathering, environmental mobility, or air dispersion properties of these various isotopes. The dose estimates for external exposure based on the air emersion dose coefficients from EPA (1993) were negligible even for the gamma emitters ^{60}Co and ^{137}m-Ba, 1.99 x 10^{-10} and 1.84 x 10^{-11} mrem, respectively (***Table I.2.***). (Only a few of the daughter isotopes are shown since the dose from the ^{235}U and ^{238}U decay chains, predominantly alpha emitters, with the exception of the small fractions of ^{234}Pa produced, result in doses three order of magnitude below the major gamma emitters ^{60}Co and ^{137}m-Ba. Because external dose is so small, the total estimated dose to the off-site receptor is essentially the sum of the doses listed ***Table I.1.*** for inhalation: 8.6 x 10^{-5} mrem/year. This is an insignificant contribution to the 7 x 10^{-3} mrem off site dose impact reported in the 1999 DOE ORR ASER for all stack emissions of radionuclides. It emphasized, however, the dose estimated here is based on extremely conservative assumptions including: no dispersion, mixing or precipitation of contaminates between the application site and off site receptor and an infinitely erodible surface that is only 50% vegetated. The dose impact from these sites should be much lower that modeled here and the values reported in ***Table I.1.*** should be considered bounding conditions only.

Exhibit I.2. Dose Intake and External Exposure Models

COMMITTED DOSE FROM INHALATION

$$Dose\ (mrem) = h_i \times IR \times \frac{A_0}{PEF} \times \frac{(1 - e^{-kT})}{k}$$

DOSE FROM EXTERNAL EXPOSURE (AIR IMMERSION)

Parent Isotope dose Parent Isotope dose at T

$$Dose\ (mrem) = h_e \times \frac{A_0}{PEF} \times \frac{(1 - e^{-kT})}{k}$$

Daughter Isotope dose after time T

See Bateman equations (EPA 1993)

Parameter	Definition and Units
h_i	committed dose equivalent per unit intake (mrem/pCi) (EPA 1988)
h_e	air immersion dose coefficient (mrem-m^3/pCi-s) (EPA 1993)
IR	inhalation rate of 20 m^3/day
A_0	activity in soil at t=0
T	days of exposure: 365
k	decay constant in days: $0.693/t_{½}$(days)

Table I.2. External exposure

Isotopes *	Activity-Soil(t=0) pCi/g soil	Time Integrate Exposure pCi-yr/m^3	h_e mrem-m^3/pCi-s	mrem
Co-60	0.214	1.18E-07	5.36E-11	1.99E-10
Cs-137	0.083	4.57E-08	3.19E-12	4.59E-12
Ba-137	-	4.25E-08	1.38E-11	1.84E-11
U-235	0.016	8.81E-09	2.66E-12	7.39E-13
Th-231	-	8.81E-09	1.93E-13	5.36E-14
Pa-231	-	3.73E-13	1.93E-13	2.27E-18
U-238	1.861	1.02E-06	1.07E-14	3.47E-13
Th-234	-	1.02E-06	1.25E-13	4.03E-12
Pa-234m	-	1.02E-06	2.66E-13	8.57E-12

*Only Co-60, Cs-137, U-235 and U-238 are routinely sampled and analyzed in application site soils

REFERENCES

EPA 1988, Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors
For Inhalation, Submersion, And Ingestion: Federal Guidance Report No. 11.

EPA 1991, Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual (Part B, Development for Risk-Based Preliminary Remediation Goals).

EPA 1993, External Exposure to Radionuclides in Air, Water, And Soil: Federal Guidance Report No. 1

EPA 1995, Health Effects Summary Table, Table 4, Radionuclide Carcinogencity - Slope Factors